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# Trends in hybrid cucumber development

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## Abstract

Cucumber which belongs to the family Cucurbitaceae, is an important vegetable crop with regard to production value. Its immature fruits are mainly consumed as salad, for making pickles, preparation of cosmetic items, soap and cream. Due to their high-water content, they have refreshing properties. Breeders have vigorously pursued improvements in terms of yield, disease resistance, fruit quality and other economically important traits. This crop exhibits high degree of cross-pollination, wide range of genetic variability in vegetative and fruit characters. A number of studies has been done in relation to genetic improvement, resistance for biotic, abiotic stresses, mutation breeding and on biotechnological aspects. In this background, this review deals with the breeding achievements in cucumber and a special emphasis has been laid on the exploitation of genetic resources for the development hybrids with desirable traits.


**Key words:** Breeding, cucumber, genetic resources, hybridization and pollination

## Introduction

Cucurbits are composed of 118 genera and 825 species and primarily distributed in tropical and subtropical regions of the world (Wang et al. 2007). Globally, watermelon (*Citrullus lanatus),* cucumber (*Cucumis sativus)* and melon *(Cucumis melo)* tops the list of cucurbits in terms of production. The genus *Cucumis* includes 30 wild and cultivated species that are spread throughout the world and has two major species: cucumber and melon. Cucumber (*Cucumis sativus* L., 2n = 2 x =14) is a widely cultivated and most popular vegetable in the Cucurbitaceae family. Cucumber is well known as a fresh market vegetable, primarily grown for its edible tender fruits used as salad and even grown on commercial scale all around the world. Cucumber is a creeping vine which wraps around trellises or other supporting frames with the help of thin and spiraling tendrils. Its fruit is roughly cylindrical, elongated with tapered ends, and the large leaves form a canopy over the fruit. Cucumber contains usually more than 90% water. Sex expression is an important factor which has a positive effect on yield and constitutes a major component of cucumber improvement programs (Serquan et al. 1997).

## Origin and Evolution

Cucumber is thought to be indigenous to India. Cucumber has been cultivated in India for over 3000 years and in Eastern Iran and China probably for 2000 years. China is a secondary center of genetic diversification of *C. sativus.* Cucumber was introduced from India to China, North Africa and South Europe, and from Europe to New World by early travellers and explorers. It was introduced to Tropical Africa by the Portuguese (Staub et al. 1999 and Wang et al. 2007). The wild relative of cucumber *C. sativus var. hardwickii* is found in Himalayan foothills of India which is fully cross compatible with cucumber. Several accessions of *C. sativus var. hardwickii* have been collected and it was found that its range of variability fell within that of *Cucumis sativus.* This fact supports that *C. sativus var. hardwickii* is either a feral or progenitor of cultivated cucumber and India has been the primary centre of origin for cucumber. The subgenus *Cucumis* includes Sino–Himalayan species like *C. sativus* (2n = 2x = 14) and *C. hystrix* Chakr. (2n = 2x = 24). The wild *C. hystrix* has unique genetic traits and found only in Yunnan province of Southern China and (Prohens and Nuez 2008). *C. sativus* has several botanical groups like var. *sativus,* the cultivated cucumber and var. *hardwickii,* the wild form. Commercial cucumber, referred to as *Cucumis sativus* is thought to have originated in the southern Himalayan foothills region of Asia.

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## Distribution and Cytogenetics

Cucumis has more than 30 species of which cucumber and melons are economically important origin in India having 2n= 14. Jaffrey (1980) classified the entire genus *Cucumis* in two subgenera:-

1) Subgenus Cucumis x=7, 3 or 4, Sino-Himalayan species including *C. sativus* (*C. hystrix, C. muriculatus*).
2) Subgenus melo x= 12 species mostly in Tropical and Soth Africa.

a. Anguria group- Dioecious, monoecious and andromonoecious perennial or annual with yellowish or brown fruit, closely related and partially fertile interspecific hybrids. *C. anguria, C. dispaceus, C. prophetarum, C. myriocarpus, C. sacleuxii.*

b. Metuliferus group- Monoecious, annual with red spiny fruits, *C. metuliferus.*

c. Melo group- Monoecious, andromonoecious perennial or annual with smooth fruit. *C. melo, C. sagittatu* (syn. *C. anglolensis*), *C. dinteri, C. humifructus.*

d. Hirsutus- dioecious perennials with smooth orange fruit, *C. hirsutus*.

The evolution of the genus Cucumis, in particular the relationship between two basic numbers x=7 and x=12 is not clear. Whitaker (1930), Bhaduri and Bose (1947) assumed that species with 2n= 24 chromosomes have arisen from species with 2n=14 chromosomes by fragmentation. Trivedi and Roy (1970), however, are of the opinion that by fusion of chromosomes with (sub) terminal centromere species with 14 chromosomes have arisen from species with 24 chromosomes.

## Genetic divergence

Genetic diversity is the amount of heritable variability between varieties or populations of organisms. This variability arises due to differences in DNA sequences, biochemical characteristics like isoenzyme properties, physiological properties like resistance to illnesses and growth rate, and morphological characters such as leaf type and flower colour. Selection, mutation, genetic drift and gene flow also affect genetic diversity in different populations by acting on the alleles in these populations. The degree of genetic diversity in *C. s.* var. *sativus* is relatively low compared with other cross-fertilized species of *Cucumis* (Esquinas-Alcazar 1977 and Knerr et al. 1989). Genetic markers (morphological and biochemical) have been employed to characterize the genetic diversity present in the cucumber collection (Knerr et al. 1989 and Meglic et al. 1996).

## Pollination and Fertilization

Cucumber is basically monoecious in nature. However, cultivars having gynoecious or predominately female sex expression have been subsequently bred for commercial cultivation. Both male and female flowers are yellow with 5 petals. Male flowers have no pistils but 3 stamens. Female flowers have well developed pistils with three bilobed stigmas, a style and a three-chambered ovary but stamens are reduced and nonfunctional. The stigma is receptive throughout the day but most receptive in early morning (Seaton et al 1936). Female flowers produce a higher volume of nectar than male flowers, but sugar concentration is higher in male flowers (Collison 1973). Flowers open in the early morning around 5:30 to 7:00 am and pollination is generally completed by noon. Pistillate flowers are receptive in the morning or upto mid day on the day of opening. Gynoecious genes was more

**Table 1:** Genetic resources for different traits in cucumber (Rai and Rai 2006)

| Trait | Promising accession (s) |
|---|---|
| High yield | Chamba Local-11, EC-27080, Dhaneswar-2, Kheera Bharasati, VRC-11, FLCU-4, Patna-3, CH-124, CH-123, CH-136, HAC-71, HAC-31, HAC-26, UHF-Sel, LC-1, Ranch-9, VRC-7, Bihar-10, IC-203938, RHRC-1, RHRC-2 and Market Long |
| Extended shelf life (4 months) | IC-203838, 203839 |
| Early determinate | EC-398030 |
| Gynoecious line | EC-382737, 329300 and 382739 |
| Powdery mildew resistance | Poinsett, Yomaki, Spartan and Saladpi-197088 |
| Watermelon mosaic virus (WMV-1 & WMV-2) resistant | Table green and Surinam |
| Bacterial wilt resistant | PI-200815, PI-200818, 79-48 and 79-42-24 |
| Multiple disease resistant | EC-320526 |
| Anthracnose resistant | PI-197087 |
| Angular leaf spot resistant | PI-200815, PI-169400, MSU-9402 and GY-14A |
| Cucumber green mottle mosaic virus | *Cucumis anguria* |
| Cucumber mosaic virus | TMG-1, Chinese Long, Chinese Long Green, Shamrock, Wisc-SMR 12, 15, 18, Elem |

**Table 2:** List of genes controlling different traits in cucumber (Nayar and More 1998 Ram 1998)

| Trait | Importance | Gene symbol assigned |
|---|---|---|
| Bushy | Short internodes | by or bu |
| Compact | Reduced internodal length | cp |
| Compact-2 | Short internodes | cp-2 |
| Determinate habit | Short vine | de |
| Determinate habit-2 | Short vine | de-2 |
| Female | High degree of pistillate sex expression | F or Acr |
| Gynoecious | High degree of pistillate sex expression | gy |
| Trimonoecious | Producing male, female and bisexual flowers | Tr |
| Andromonoecious | High degree of male expression | m |
| Multi pistillate | Several pistillate flowers per nodes | mp, mp-2 |
| Parthenocarpy | Sets fruit without pollination | pc |
| Black or Brown Spine | Fruit quality | B Dominant to white spines |
| Black Spine-2 | ” | B-2 Interact with B to produce $F_2$ of 15 black: 1 white |
| Black Spine-3 | ” | B-3 Interact with B-4 to produce $F_2$ of 9 black: 7 white |
| Black Spine-4 | ” | B-4 Interacts with B-3 |
| Cucurbitacins | Bitter free, lacking cucurbitacin | bi |
| Dull fruit skin | Fruit colour | D Dull skin of American cultivars dominant to glossy skin of European cultivars |
| Green mature fruit | Fruit colour | gn |
| Numerous spines | Fruit quality | ns Few spines is dominant to numerous spines |
| Male sterile-1,2 | Male sterlity | ms-1,ms-2 |
| Bacterial wilt | Resistance to *Erwinia tracheiphila* | Bw |
| CMV resistance | Virus resistance | Cmv |
| Cladosporium resistance | Resistance to scab | Ccu |
| Downy mildew resistance | Disease resistance | dm-1, dm-2, dm-3 |
| Nematode resistance | Disease resistance | mj |
| Powdery mildew resistance-1,2,3 | Disease resistance | pm-1,2,3 |
| Powdery mildew resistance-h | Resistance expressed by hypocotyl | pm-h |
| Anthracnose | Disease resistance | Ar |
| *Pseudomonas lachrymans* | Disease resistance | psl |
| *Colletotrichum lagenarium* | Disease resistance | cla |
| *Corynespora melonis* | Disease resistance | Cm |
| Zucchini yellow mosaic virus | Disease resistance | zymv |
| Fusarium wilt | Disease resistance | Foc |

stable under low temperature of 24-25°C and photoperiod upto 12 hr (More and Munger 1986). Light intensity and time of the day influenced anthesis of cucumber more than temperature. The female and male lines are grown in alternate rows in the ratio of 4:1. Cucumbers may also be pollinated by bees.

Some cultivars of cucumber are parthenocarpic *i.e.* formation of seedless fruit without pollination. Pollination for these cultivars degrades the quality. In case of traditional cultivars, male flowers are produced earlier then female flowers, but in almost equal numbers. Newer gynoecious hybrid cultivars produce almost all female flowers. They may have a pollenizer cultivar interplanted, and the number of beehives per unit area is increased, but temperature changes induce male flowers even on these plants, which may be sufficient for pollination to occur. In order to avoid killing off insect pollinators, insecticide applications for insect pests must be done with extra care. Wehner and Kumar (2012) reported that 'NC-Sunshine' is a new monoecious slicing hybrid cucumber with a high percentage of pistillate nodes. Though the percentage of pistillate nodes is high, a pollenizer might be required to maximize pollination which leads to increase in total and early yield. Golabadi et al. (2019) reported that pollination at 8:00 9:45 AM, led to higher amount of full seed weight in contrast to other times of pollination. Increasing crossed node spacing from 2 3 to 4 5 nodes led to an increase in the number of empty seeds, which was ascribed to the reduced seed production. The highest amount of number of seeds per fruit, seed weigh and number of full seeds were obtained when young male flowers were used.

**Table 3:** Main sex types present in cucumber (Singh 2011)

| Sex form | Flower type |
|---|---|
| Hermaphrodite | Bisexual flowers. |
| Monoecious | Staminate and pistillate flowers. |
| Androecious | Only staminate flowers. |
| Gynoecious | Only pistillate flowers. |
| Andromonoecious | Staminate and hermaphrodite |
| Gynomonoecious | Pistillate and hermaphrodite |
| Trimonoecious | Androecious, Gynoecious & Hermaphrodite |

Plant micro-environmental factors control expressions of flowering genes of plants of Cucurbitaceae. The ratio of number of female flowers to male flower was higher in favourable condition and less under stress micro-environmental condition. The higher the temperature, the less the moisture content in the soil, within field capacity to plant wilting point, and the less the inter plant spacing, the higher was the maleness, when the intensity of sunshine and day length remained the same. The expression of female flowering gene was more stress sensitive (Das 2008). Ito and Saito (1957) reported that female flower formation of cucumber is hastened by IAA, NAA and 2,4-D. NAA was reported to be the most effective (Ito and Saito 1956 and Trebitsh et al. 1987). Gibberellin (GA), aminoethoxyvinylglycine (AVG) and silver ions can promote staminate flower development on gynoecious plants (Fuchs et al. 1977, Lower 1978, Den Nijs and Visser 1980, Hunsperger et al. 1983, More and Hunger 1986 and Staub and Crubaugh 1987). Tiedjens (1928) found that pistillate flowering is favored by low light intensity and short photoperiod. An interaction of short days and cool nights favors formation of more 12 pistillate flowers (Ito and Saito 1957, Delia et al. 1982 and Odland and Groff 1962). Kie³kowska (2013) tested the effects of plant growth regulators (PRGs) on the induction of flowering and sex expression in micropropagated cucumbers are presented. The highest number of male flowers (6.0 ± 0.7 per plant) was produced by cv. Kmicic F1 on the Murashige and Skoog (MS) medium supplemented with 4.0 ìM kinetin. The highest number of female flowers (3.1 ± 0.3) was also observed in cv. Kmicic F1 on either control (PRG-free) medium or medium supplemented with 6.4 ìM indole-3-acetic acid (IAA).

## Interspecific Hybridization

Interspecific hybridization is used to improve crops by transferring specific traits, such as pest and stress resistance, to crops from their wild relatives (Bowley and Taylor 1987). Attempts to introduce valuable traits from wild *Cucumis species* into cultivated cucumber and melon through conventional hybridization have not suceeded because of interspecific cross incompatibilities (Whitaker 1930, Smith and Venkat Ram 1954, Deakin *et al.* 1971 and Fassuliotis and Nelson 1988). Biotechnological techniques such as somatic hybridization have been suggested as possible tools for overcoming interspecific hybridization barriers in *Cucumis* (Tang and Punja 1989 and Chatterjee and More 1991). Chen *et al.* (2002) studied reciprocal differences in interspecific hybridization in *Cucumis*. The fertility of reciprocal plants was greatly different. When *C. hystrix* was used as female, the tetraploid (2n=38)/diploid (2n=19) plants had higher fruit sets, and even the amphidiploidy plants could produce viable seeds. However, when the cucumber was used as female, both tetraploid/diploid plants were highly sterile and had very low fruit sets. Chen et al. (2005) developed a new pickling cucumber line 7012A through interspecific hybridization of cultivated cucumber Beijingjietou with the *Cucumis* wild species *C. hystrix* and subsequent backcrossing of the hybrid to cucumber and selection from the selfed progenies. This line was used to cross with an elite American pickling cucumber line (7011A) to produce $F_1$. The results indicated that the $F_1$ has significant heterosis over its parents in yield and growth vigour. The plants set uniform fruits with good quality and highest yield.

Tak et al. (2016) reported that five best hybrids (L3xT3, L3xT2, L2xT2, L12xT1 and L3xT1) identified based on *per se* performance on pooled basis for total yield per vine. Appreciable heterosis was observed over better and top parent for most of the characters studied. Best three economic hybrid L3 x T3, L7 xT1 and L6 x T2 showing 10.75%, 22.30% and 41.39% economic heterosis for total yield per vine, T.S.S and for fruit length respectively, may be exploited for commercial cultivation.

## Mutation Breeding

Mutation is a sudden heritable change in a characteristic of an organism. This definition requires that the change in the characteristic be heritable, but it does not specify the genetic basis of the heritable change. Mutations arise normally in large populations but are usually considered to be rare events. Seeds of cucumber cv. M15 were treated with 0.05% ethylenamine for 21h, and selection

**Table 4:** Wide-cross attempts between cultivated and wild *Cucumis species*

| Cross | Result | Source |
|---|---|---|
| *C. sagittatus* × *C. melo* | Embryos only | Deakin et al. 1971 |
| *C. metuliferus* × *C. melo* | Embryos only | Fassuliotis 1977 |
| *C. sativus* × *C. melo* | Globular stage embryos only | Szczytt and Kubicki 1979 |
| *C. metuliferus* × *C.melo* | Fertile $F_1$ | Norton and Granberry 1980 |
| *C. prophetarum* × *C. melo* | Fruit with inviable seeds | Singh and Yadava, 1984 |
| *C. zeyheri* × *C. sativus* | Fruit with inviable seeds | Custers and Den Nijs 1986 |
| *C. sativus* × *C. metuliferus* | Embryos only | Franken et al. 1988 |
| *C. melo* × *C. metuliferus* | Embryos only | Soria et al. 1990 |
| *C. sativus* × *C. hystrix* | Sterile plants (2n and 4n) | Chen et al. 1997 |
| *C. hystrix* × *C. sativus* | Fertile plants (4n) | Chen et al. 1998 |

for resistance to *Meloidogyne* spp. revealed that 7.6 % of plants were resistant (Udalova and Prikhod'Ko 1985). Swarna Ageti variety of cucumber has been developed with the exploitation of mutation breeding by HARP, Ranchi and it has resistance to powdery mildew. Gamma irradiation of 0.1 kGy stimulated the development of higher number of haploid embryos in cucumber (Faris et al. 1999). Chen et al. (2018) optimized the conditions of EMS mutagenesis on inbred line 406 which included treatment of seeds at 1.5% EMS for 12 h. We obtained a number of mutant lines showing inheritable morphological changes in plant architecture, leaves, floral organs, fruits and other traits through M1, M2 and M3 generations. The F2 segregating populations were constructed and analyzed. We found that a short fruit mutant and a yellow-green fruit peel mutant were both under the control of a single recessive gene, respectively. These results provide valuable germplasm resources for the improvement of cucumber genetics and functional genomic research.

## Heterosis Breeding

In cross-pollinated crops, exploitation of heterosis (hybrid vigor) is an important aspect of its improvement. In monoecious crop, the development of $F_1$ hybrids is a simple and less costly. The seed requirement per hectare for commercial cultivation would be low and cost effective due to cultivation at wider spacing. Therefore, cucumber offers greater scope for exploitation of hybrid vigour on commercial scale. In cucurbits, high productivity is one of the important aspects of heterosis, but early maturity is equally important especially in cucumber and summer squash, because of the economic dimensions in terms of the price of the early produce. Manifestation of heterosis has attained the highest perfection in cucumber by utilization of gynoecious sex forms, which enabled every flowering node to produce a fruit. Hayes and Jones (1976) reported that first generation crosses in cucumber exhibited high parent heterosis due to increased fruit size and number of fruits per plant. They provide early and higher yield, uniformity in fruit shape, size, colour, better quality and resistance to several disease controlled by dominant genes. Airina et al. (2013) reported that the hybrids EC 709119 × IC 538155 followed by EC 709119 × IC 527427, EC 709119 × IC 538186 and EC 709119 × IC 410617 exhibited high heterobeltiosis for fruit yield and fruits per plant. These hybrids can be advanced for further testing for commercial exploitation of hybrid vigour. Tiwari and Singh (2016) evaluated twenty-four $F_1$ hybrids derived from 11 diverse cucumber genotypes to study the extent of heterosis and combining ability on earliness and yield characters. Appreciable heterosis in desirable direction was found in cross PCUCP-3 × PCUC-15 for earliness, whereas Cross Kian × PCUC-15 showed maximum number of fruits per plant and fruit yield. Moreover, Simi et al. (2017) observed highest positive heterotic effect for no. of fruits per plant was observed in Modhumoti × Baromashi (20%). The highest heterobeltiosis effect was found in hybrid Himaloy × Yuvraj (24.5%) followed by Sobujsathi× Khira (11.2 %), Modhumoti × Baromashi (10.0 %). Four crosses exhibited significant positive better parent heterotic effect for this trait and the combination Sobujsathi × Baromashi had the maximum heterosis on yield (47.6%). The maximum heterobeltiosis effect was found in Shila × Khira (27.73 %) followed by Modhumoti × Hero (15.14%) and Modhumoti × Khira (10%) for fruit yield. Further, Malav et al. (2018) carried out study on heterosis and combining ability for fruit yield and its components in 42 $F_1$ hybrids of cucumber obtained from a full diallel involving three gynoecious and four monoecious parents and reported that Hilton × Swarna Sheetal exhibited high heterosis for fruit yield per plant. Sahoo and Singh (2020) used line × tester mating design to determine the magnitude of heterosis for earliness, yield and yield related traits in cucumber. Appreciable heterosis was observed over better parent and standard parent for most of the characters studied. The best $F_1$ hybrids reported were PCUCP-4 × PCUC-8 for yield per plant, PCUCP-3 × PCUC-8 for average fruit weight and PCUCP-1 × PCUC-8 for node number to first female flower over standard check Pant Khira-1 and these three hybrids may be exploited for commercial cultivation.

## Breeding for Multiple Disease Resistance

Development of cucumber hybrids with multiple disease resistance is the most effective and straightforward way of plant protection. The choice of accurate parental lines is the first and foremost step towards successful development of hybrids with desirable traits. Breeding for disease resistance was emphasized in USA with the development of CMV resistant cultivar Shamrock during 1937. In 1955 resistance to scab and CMV were combined in the line Wisconsin SMR-12. Phenomenal success has been accomplished in cucumber by Peterson and his associates (1982) in Wisconsin (USA), where resistant line, WI2757 had been developed carrying resistance to as many as nine diseases (powdery mildew, downy mildew, scab, anthracnose, angular leaf spot, bacterial wilt, target leaf spot, CMV and fusarium wilt). Additional resistances were identified and eventually combined in the lines Sumter with resistances to 7 diseases and Wisconsin 2757 with resistance to 9 diseases. Kushnereva (2008) has developed cucumber lines and hybrids combining complex resistance to 5 or 6 diseases (downy mildew, powdery mildew, scab, blotch or target spot, Fusarium wilt) with other economically important traits (parthenocarpy, improved fruit quality, etc.). Disease resistant traits are quantitative traits that are controlled by multiple genes, which are generally located in multiple effect quantitative trait loci (QTL). The Gy14 and WI2757 cucumber inbred lines are resistant to multiple diseases and used in the QTL mapping studies for downy mildew, angular leaf spot and anthracnose resistance and further map-based cloning to identify the candidate genes for the resistant loci (Wang et al. 2019). QTL studies have also been carried out by involving WI2757 line for resistances to diseases such as powdery mildew, downy mildew, fusarium wilt, scab and different potyviruses (Wang et al. 2020).

## Breeding for Salt and Drought Stress

Sacala et al. (2008) studied effect of water stresses on growth, nitrogen and phosphorus metabolism in cucumber seedlings. Under PEG treatment reduction in cucumber drymass is lesser than in fresh mass, whereas under salt stress decrease in dry weight of cucumber shoots was more pronounced than in fresh mass. NaCl and PEG caused approximately 40% decrease in fresh weight of cucumber shoots (hypocotyl + cotyledons) but there was 45% decrease in dry weight under salt stress and 27% reduction under PEG treatment. Salt stress is more deterimental than sole osmotic stress (PEG treatment). Primary consequence of salinity and drought is osmotic stress, which creates decrease in water availability. Turgor of cucumber seedlings grown under PEG and NaCl was not reduced and water contents in different organs were similar to these in control plants.

## Breeding for Low Temperature

Cucumber is one of the more chilling-sensitive crops. It does not grow at temperatures below 16°C and is susceptible to chilling injury, especially at temperatures below 6°C. As a result, in many geographical regions where the crop is planted before the risk of frost has ended (e.g., northern Europe and eastern United States), the cucumber crop is at risk in early spring plantings. Younger seedlings (cotyledons stage) are less sensitive to chilling injury than seedlings at the first true fully expended leaf (Smeets and Wehner 1997). Cultivars with low temperature tolerance are currently unavailable, although differences in response to chilling temperatures were found among the cultivars present on the market (Cabrera et al. 1992). With the development of protected horticulture, cucumber breeding for chilling tolerance has become important. There are just a few literatures on inheritance of cucumber chilling tolerance. Two chilling tolerant lines (Nongdachunguang, Beijing cigua) have been identified and used in genetic study for chilling tolerance. Smeets and Wehner (1997) identified chilling resistance in AR75-79 and 'Chipper', and also developed a method for testing the chilling resistance in cucumber seedlings. Chung et al. (2003) investigated the inheritance of chilling injury in progenies of resistant 'Chipper' and 'AR75-79' crossed with susceptible 'Gy 14' and reported that chilling resistance was maternally inherited. Wadid et al. (2003) reported that PI 267742 showed best mean performance for total yield and related traits under low temperature condition and this parent could be improved and used in producing a low temperature tolerance variety. Klosinska et al. (2013) reported that cucumber cultigens B 5669, PI 390953, and PI 246903 showed low temperature tolerance. Among them B 5669 may become the most desirable to breeders as it exhibits cold germinability combined with good fruit quality traits.

## Breeding for Insect Pest Resistance

Cucurbits are highly susceptible to several biotic and abiotic stresses. Simple selection method has been used mostly for developing resistant varieties in cucurbits. The growing of resistant varieties has been a major successful control tactic against the vegetable pests, because of the difficulty of using pesticides on these edible plants. Da Costa and Jones (1971), Kooistra (1971) and Howe et al. (1976) supported this view. In cucumber, single recessive gene *bi* (bitter free) conferred resistance to different species of cucumber beetles (De Costa and Jones 1971). Munshi *et al*. (2008) studied genetics of resistance to Cucumber mosaic virus (CMV) in *Cucumis sativus* var. *hardwickii*, the wild progenitor of cultivated cucumber. As compared to 31 genotypes of *C. sativus* var. *hardwickii* collected from 21 locations in India, IC-277048 (6.33%) was recorded with the lowest mean percent disease intensity (PDI). The results revealed that CMV resistance in *C. sativus* var. *hardwickii* was controlled by a single recessive gene. Considering the cross compatibility between *C. sativus* var. *hardwickii* and cultivated cucumber, with the help of simple backcross breeding resistance trait can be easily transferred to cultivated species.

## Breeding for Disease Resistance

Velkov and Alexandrova (2002) found that the accessions PI 192940, 73-508, Nanchi White Spine, Linia 75-6, Bursa 94-16, Polaris DPM, Linia 61 and Poinsett were suitable sources for combining resistance to powdery mildew with good fruit quality. Velkov et al. (2009) found that three pickling (W 1922, LV 41, Sumter) and eight salad genotypes (Santo, Long Green, Stono, Polaris S, Sc50, Sagami Hanjioro, Poinset DPM, Taichong Mou Gua) showed combined resistance to both powdery mildew and downy mildew pathogens. Call et al. (2012) screened cucumber for resistance to downy mildew caused by *Pseudoperonospora cubensis* and found PI 605996, PI 330628, and PI 197088 as the most resistant cultigens over all environments. The inheritance of cucumber disease resistance described by Jin'an (2004) as:

- *Pseudoperonospora cubensis* (downy mildew) resistance either by multigenes or a single gene.
- *Sphaerotheca fuliginea* (powdery mildew) resistance by recessive multigenes.
- *Fusarium oxysporum* f.sp. *cucumerinum* (Fusarium wilt) by single dominant or recessive gene.
- *Phytophthora melonis* by resistance by polygenes.
- *Colletotrichum orbiculare* by single dominant gene or recessive gene.
- *Pseudomonas syringae* pv. *lachrymans* (Bacterial angular leaf spot) either by polygene or single recessive gene.
- *Cladosporium cucumerinum* (Scab) by single dominant gene.

## Breeding for Nematode Resistance

There are several species of *Meloidogyne* (Root knot nematode) affecting many cucurbits. Efforts to transfer resistance from *C. metuliferus* have not been successful (Fassuliotis 1977, Norton and Granberry 1980). *C. hardwickii* carries resistance to *M. javanica*. Chen *et al*. (2001) carried out study to identify resistance of the wild cucumber species, *Cucumis hystrix* to the root knot nematode and to evaluate the transmission of resistance to progenies of its interspecific hybrids with cucumber (*C. sativus*). Reported that *C. hystrix* was highly resistant and *C. sativus* was highly susceptible to the pest. The resistance was shown to be partially transmitted to the $F_1$s when the interspecific reciprocal crosses were made, and it was further transmitted to the $BCF_1$ progeny when the chromosome-doubled $F_1$s were backcrossed as the resistance donor to the cultigens.

## Polyploidy Breeding and its Achievements

Cucurbits generally are regarded displaying partial auto- and partial allogamy and this phenomenon is often cited as a possible reason for less number of natural polyploids in the family. Cucumber haploids are infertile and do not undergo spontaneous diploidization (Przyborowski and Szczytt 1994). Kubicki (1962) found the optimum duration for the production of tetraploids using cucumber seeds soaked in a 1% and 0.4 to 0.7% solution of colchicine was 6 to 24 hours and 12 to 24 hours, respectively. Induced polyploidy has facilitated gene transfer between some related species when crossed at different ploidy levels (Stoskopf et al. 1993). Autotetraploids of *Cucumis sativus* and *C. metuliferus* were obtained at the highest rate when seeds were immersed in 0.5% colchicine for a period of 6 to 8 hrs. (Walters and Wehner 2002).

## In-vitro Breeding

Caglar and Abak (1999) induced haploid cucumber embryos by pollination with irradiated pollen and cultured on E20A medium under aseptic conditions. They found that the regenerative ability of embryos was higher at advanced stages (60% in the first year and 80% in the second year) than at globular stage. These embryos also produced haploid plants rapidly (in 3.5 days). In vitro pollination and fertilization have been used to overcome pre-zygotic (factors hindering effective fertilization) and post-zygotic (barriers occurring during or after syngamy) cross-incompatibility in the genus *Cucumis* (Ondrej et al. 2002). Germination of isolated pollen grains in culture is a prerequisite for several biotechnological manipulations in cucumber (Vizintin and Bohanec 2004). Crossing barriers in inter-specific hybridization within the genus *Cucumis* can be overcome through in vitro pollination. Pollen grains were isolated directly from mature male flowers and were cultured with mature ovules. The developing ovules when became enlarged and green were transferred to media supporting embryogenesis. They found caseinhydrolysate to be the

**Table 5:** Following are the resistant sources identified against different insect-pests

| Insects | Resistant sources | References |
|---|---|---|
| Striped and spotted cucumber beetles | Nappa 63, Ohimo | Wiseman et al. (1961), Nath (1965) |
| Cucumber beetle | White Wonder, Ashley Wisconsin 2757 | Brett and Sullivan (1970), Peterson et al. (1982) |
| White fly | Ohio MR 200, PI 220860 | De Ponti (1979) |
| Squash vine borer | National Pickling, Straight Eight | Miller (1956) |
| Aphid | EC 7050, Extra Early Green Prolific | Lal (1979) |
| Spider mites | Hybrid Long Pickle | Kooistra (1971) |
| Vegetable leaf miner | Nappa 63, PI 200815, PI 279465 | Brett and Sullivan (1970), Eason and Kennedy (1980) |

**Table 6:** Resistant sources identified for different diseases

| Diseases | Resistant sources | References |
|---|---|---|
| Anthracnose | PI 175111, 175120, 183308, PI 197087 | Barnes and Epps (1952) |
| Powdery mildew | PI 200815, PI 200818, PI 197088, Natsufushinari, Spartan Salad, Poinsett, Yomaki, WI-2757, | Fanourakis (1984) |
| Downy mildew | Poinsett, China, PI 197087, Palmetto, Pureto Rico-39 | Shimizu *et al.* (1963) |
| Scab | Highmoor, Amato and Prosos | Andeweg (1956) |

most beneficial component during in vitro pollination and during development of fertilized ovules. To obtain high yield of potential hybrid embryos, there is a need to optimize in vitro protocol (Skalova et al. 2010). Embryo-rescue and in vitro pollination are suitable in vitro techniques for production of hybrid embryos in *Cucumis* (Navratilova et al. 2011).

**Table 7:** List of natural polyploids in *Cucumis* x=7,12

| Species | 2n |
|---|---|
| ***C. ficifolius*** | 48 |
| ***C. heptadactylus*** | 48 |
| ***C. aculeatus*** | 48 |
| ***C. figarei*** | 72 |

## Genetic Emasculation Mechanism

Genetic emasculation mechanisms have been of practical importance in cucumber (*Cucumis sativus* L.) breeding because it can facilitate $F_1$ hybrid seed production without hand pollination. Five MS forms are known:

- Gynoecious flowering (G): The G character is under the control of several loci. Usually, G is considered to be a form of sex expression rather than MS because it is one of several sex segregates (Pierce and Wehner 1990).
- Apetalous sterile mutant (*ap*): In *ap*, the corolla of both staminate and pistillate flowers are reduced, and anthers become sepal-like (Grimbly 1980). The pistillate flowers develop to their usual size and, if left unpollinated, produce parthenocarpic fruit.
- Pleiotropic pollen-aborted mutant (*ms-1*): The recessive pleiotropic gene *ms-1* determines MS in which failure of staminate flower anthesis and pollen sterility (PS) varies from 30% to 90% (Shifriss 1950). Grimbly (1980) reported that *ms-1* conditions sterility in which staminate flowers are devoid of pollen, and fertility of pistillate flowers is decreased.
- Aborted male flower type (*ms-2*): In *ms-2*, the MS plants are characterized by abortion of the staminate blossoms. In rare instances when the flowers matured to anthesis, only rudimentary anthers that contained no pollen were present (Barnes 1960, Miller and Quisenberry 1978 and Whelan 1974).
- Closed-flower type: The closed-flower variant is controlled by a recessive gene *cl*. Both staminate and pistillate flowers fail to open at maturity (Groff and Odland 1963).

Except for G, other mechanisms have not been used in hybrid cucumber seed production because their inheritance is determined by nuclear genes and because they are associated with undesirable traits such as missing corolla, malformed ovary, and closed female flowers (Grimbly 1980). Zhang et al. (1994) studied the inheritance and response to chemical and environmental factors of a new male sterile mutant in cucumber and reported that pollen sterile character controlled by a single recessive gene, assigned the tentative designation ps. It was not possible to effect changes in the expression of PS by application of cytokinin, indole acetic acid (IAA) or gibberellin ($GA_3$), and there were likewise no changes in response to temperature and fertilizer treatment. Unlike gynoecy, which is responsive to some external factors, PS is a stable characteristic.

India is the primary centre of origin for cucumber but the breeding efforts for the improvement of this crop has been rather limited. High yield has always been one of the important breeding objectives but genetic variability for yield is restricted in *Cucumis sativus*. Therefore, our focus will have to shift on *Cucumis sativus* var *hardwickii* which has been successfully utilized in USA for development of breeding lines with multiple lateral branching, sequential fruiting habit and resistance to diseases. Breeding for disease resistance should be emphasized and serious efforts should be made for development of varieties or hybrids having multiple disease resistance through gene pyramiding.

## सारांश

खीरा *कुकुरबिटेसी* परिवार का एक सदस्य है और उत्पादन मूल्य के आधार पर एक महत्वपूर्ण सब्जी फसल है। इसके अपरिपक्व फल मुख्य रूप से सलाद के रूप में, अचार, सौन्दर्य प्रसाधन वस्तुएँ, साबुन और क्रीम बनाने के लिए उपयोग किये जाते हैं। उच्च पानी की मात्रा के कारण फलों में ताजापन बने रहने का गुण पाया जाता हैं। प्रजनकों ने अधिक उपज, रोग प्रतिरोधिता, फल की गुणवत्ता और अन्य आर्थिक रूप से महत्वपूर्ण लक्षणों के संदर्भ में अधिक सुधार किया है। इस फसल में उच्च स्तर पर पर–परागण, वर्धीय अनुवांशिक विविधता और फल आधारित घटकों में आनुवांशिक परिवर्तनशीलता की विस्तष्त श्रष्खला प्रदर्शित होती है। आनुवांशिक सुधार के लिए अनेकों अध्ययन जैसे–जैविक व अजैविक प्रतिबलों के प्रति प्रतिरोधिता,

उत्परिवर्तन प्रजनन और जैव–तकनीकी पहलूओं को समाहित कर किया गया। इस समीक्षा पृष्ठभूमि में खीरा प्रजनन की उपलब्धियों से संबंधित है और वांछनीय लक्षणों के साथ–साथ संकरों के विकास के लिए आनुवांशिक संसाधनों के उपयोग पर विशेष जोर दिया गया है।

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